Lagrangian Tracer Transport and Dispersion in Shallow Tidal Inlets & River Mouths

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LONG-TERM GOALS

Long-term objectives are developing and field testing numerical models of shallow water breaking waves and wave-driven processes including mixing, currents, and transport and dispersion of tracers. Calibrated models will provide improved prediction of the fate of tracers (e.g. pollution, fine sediment, chemicals) in very shallow water.

OBJECTIVES

Objectives during the past year included continued analysis of existing data sets, and extending our existing field capability in preparation for participation in the tidal inlet/river mouth DRI

APPROACH

Wave breaking occurs most of the time on many ocean beaches. Even the most sophisticated numerical models must parameterize the highly turbulent dynamics of wave breaking, and the ensuing cascade of momentum and energy to both larger and smaller scales of motion. Our general approach is to use field observations to test and calibrate the numerical models used to simulate wave-driven beach processes. The development of new field technique and the acquisition of extensive data sets are key program elements. All aspects of the work, from pre-experiment planning to publication of results, are collaborative with students and post docs.

WORK COMPLETED

* Clark et al. (2010), an analysis of dye dispersion observations during HB06, has been published.

* Feddersen et al (2011) and Clark et (2011), a 2-part comparison of dye tracer and other observations with a Boussinesq model, have been published.

* Gorrell et al., (2011), comparing observations and model predictions of waves during the ONR/NSF supported Nearshore Canyon Experiment (NCEX, 2003) experiment, has been published.

* New drifters, mooring hardware, and a small boat equipped for shallow water sampling have been acquired for use in the Tidal Inlet/River mouth DRI experiment at New River, N.C.

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RESULTS

Recent and ongoing observations combine arrays of fixed instruments (e.g. current meters, pressure sensors, and fluorometers mounted on frames or moorings) with mobile platforms (e.g. jetskis, small boats). Additionally, Lagrangian observations of transport and mixing are acquired with water-following drifters and fluorescent dye, proxies for pollutants, chemicals from ordnance, and other tracers of interest.

Dye Tracer: Fixed (frame mounted) and mobile (jet ski mounted) methods for in situ measurement of surfzone fluorescent Rhodamine WT dye in turbid and bubbly surfzone waters were developed (Clark et al, 2009). The system can also sample chlorophyl A (Omand et al, 2009). Dye sampling jetski and fixed fluorometers were first deployed at Huntington Beach, as part of the HB06 field experiment. SIO graduate PhD student David Clark used these observations to characterize surfzone mixing (figure 1). With increasing downstream distance from the source, the alongshore-oriented dye plume widens, and peak concentrations decrease (figure 2, Clark et al, 2010). A numerical model that simulates surfzone transport and mixing (figure 3) was compared with the observations. The rate the squared plume plume widens, an estimate of the surfzone diffusivity., is well predicted (figures 5 and 6). Although the observational data base is very limited, potential parameterizations of diffusivity (as a function of wave and current conditions) are emerging.

Our most recent field observations, at Imperial Beach in Fall 2009 sampled dye plumes as long as 3km (figures 7 and 8 (top)). The jetski samples only at the sea surface, because observations indicate dye is well-mixed vertically in the surfzone. A small boat was used to sample dye concentrations over the vertical, seawards of the surfzone (figure 8, bottom). Analysis of IB09 dye observations form the core of the thesis of PhD student Kai Hally-Rosendahl.

IMPACT/APPLICATIONS

Tracer evolution and transport in the nearshore is important to Navy/Marine objectives including chemically detecting mines, avoiding contact with dangerous substances, and predicting where optical clarity will be effected by fine sediments and silt. A goal is to develop a portable (between sites) model suite that, given bathymetry and incident wave conditions, predicts (perhaps qualitatively) tracer transport and dilution.

RELATED PROJECTS

Huntington Beach (HB06) and Imperial Beach (IB09) observations and analysis were funded by ONR, NSF, and Sea Grant. The upcoming DRI observations at New River, NC will build on this framework.

Dr Falk Fedderson is co-PI on the projects discussed here, that supported HB06 and IB09 observations. Falk is sole PI on independent analysis work, descrbed in his annual report.

PUBLICATIONS (2009- present) acknowledging ONR support

Omand, M., F. Feddersen, D.B. Clark, P.J.S. Franks, J. J. Leichter , and R.T. Guza, The Influence of Bubbles and Sand on Chlorophyll-a Fluorescence Measurements in the Surfzone, Limnol. Oceanogr.: Methods7, 2009, 354–362, 2009. [published, refereed].

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Gorrell L., B. Raubenheimer, Steve Elgar, and R.T. Guza, SWAN Predictions of Waves Observed in Shallow Water Onshore of Complex Bathymetry. Coastal Engineering, V 58 (6), 510-516, 2011 [published, refereed].

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Clark, D. B., F. Feddersen, and R. T. Guza, Modeling surfzone tracer plumes, Part 2:Transport and Dispersion J. Geophys. Res., [in press, refereed]
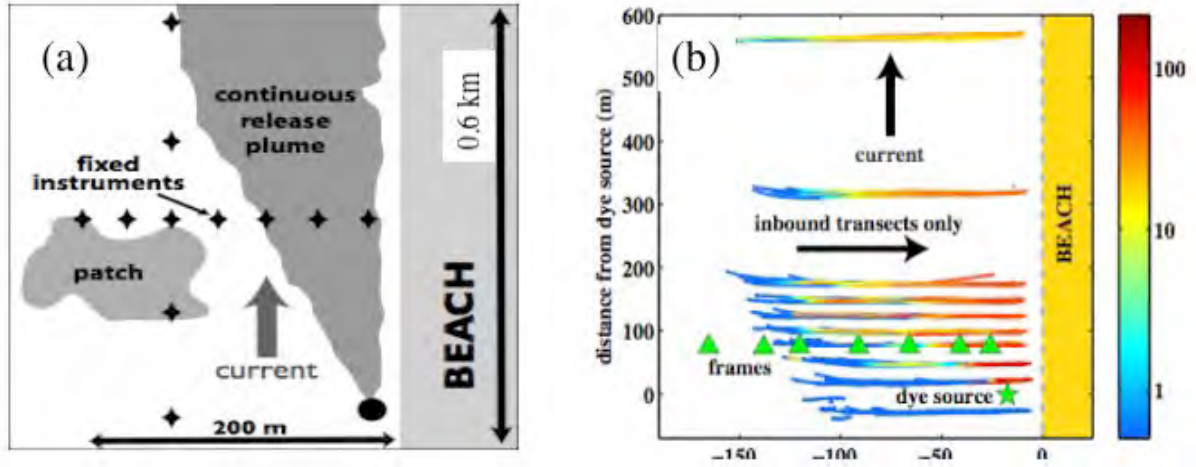
Figure 1: (a) Schematic of HB06 dye plume mixing experiment. Fixed instruments (current meters and pressure sensors) measured waves and currents on cross- and alongshore transects. Dye was measured at (usually) 4 locations with fixed fluorometers, and with a jetski. Dye was released as a single patch, and continuously forming a plume. (b) ski-sampled dye concentrations across a dye plume are indicated by colors (scale to the right). During a 4-hr plume release on 11 Oct 2006, the mean alongshore current near the shoreline was 20 cm/s, and the breaker height was 50 cm. About 10 passes were made along each transect.
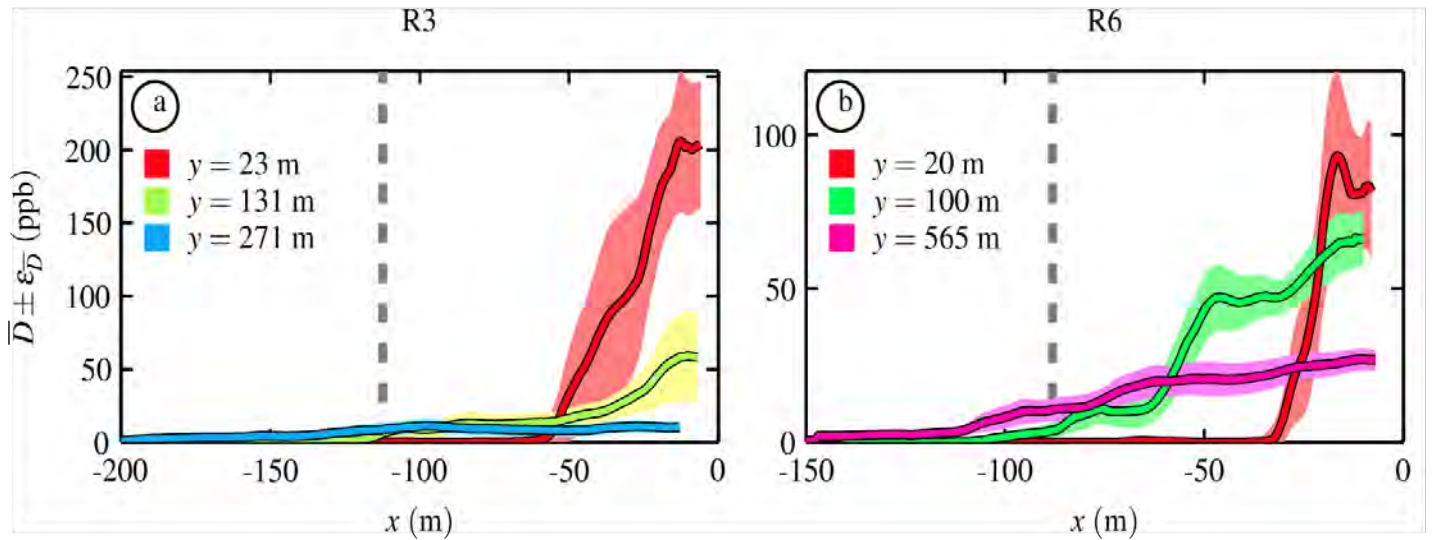

Figure 2: Mean dye profile curves D(x; yj) with lighter regions indicating range of D(x; yj) incuded in the average, for dye releases (a) R3 and (b) R6 at three alongshore distances y from the dye source (see legend). The dashed gray line indicates the seaward edge of the surfzone. Vertical scales differ.
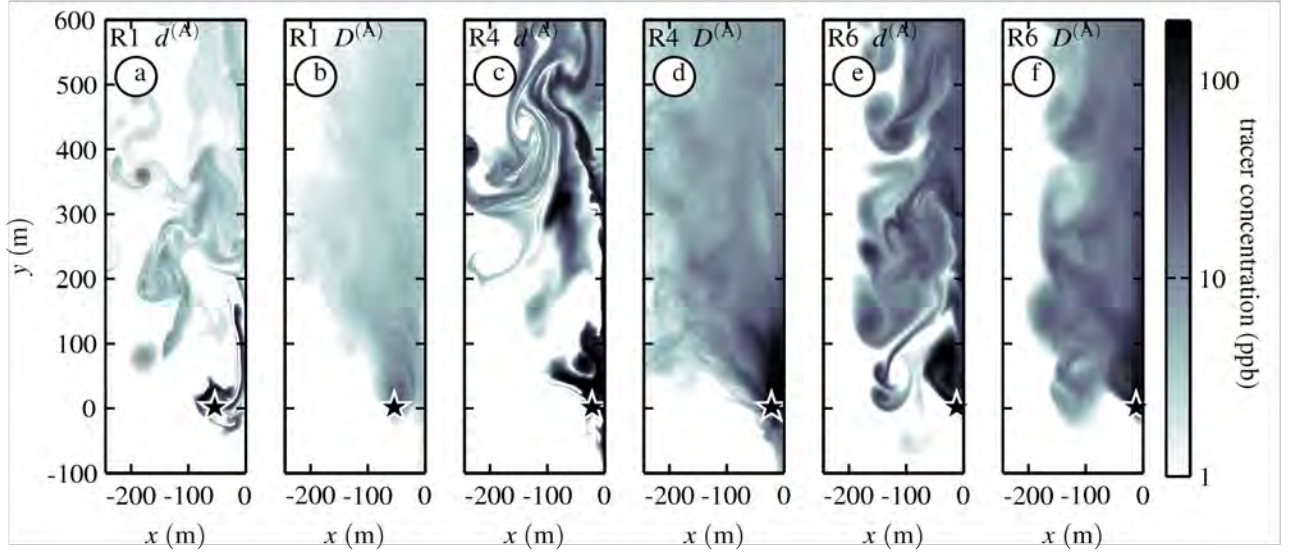
Figure 3 a, c, e) Instantaneous $d^{(A)}$ and (b, d, f) mean $D^{(A)}$ (time average over 6000–14,000 s after each tracer release begins) modeled tracer A concentration as a function of x, the cross-shore distance from the "shoreline", and y, the alongshore distance from the dye source, for (a, b) R1, (c, d) R4, and (e, f) R6. In each panel the back star indicates the cross-shore release location (x_{rl}, Table 1).
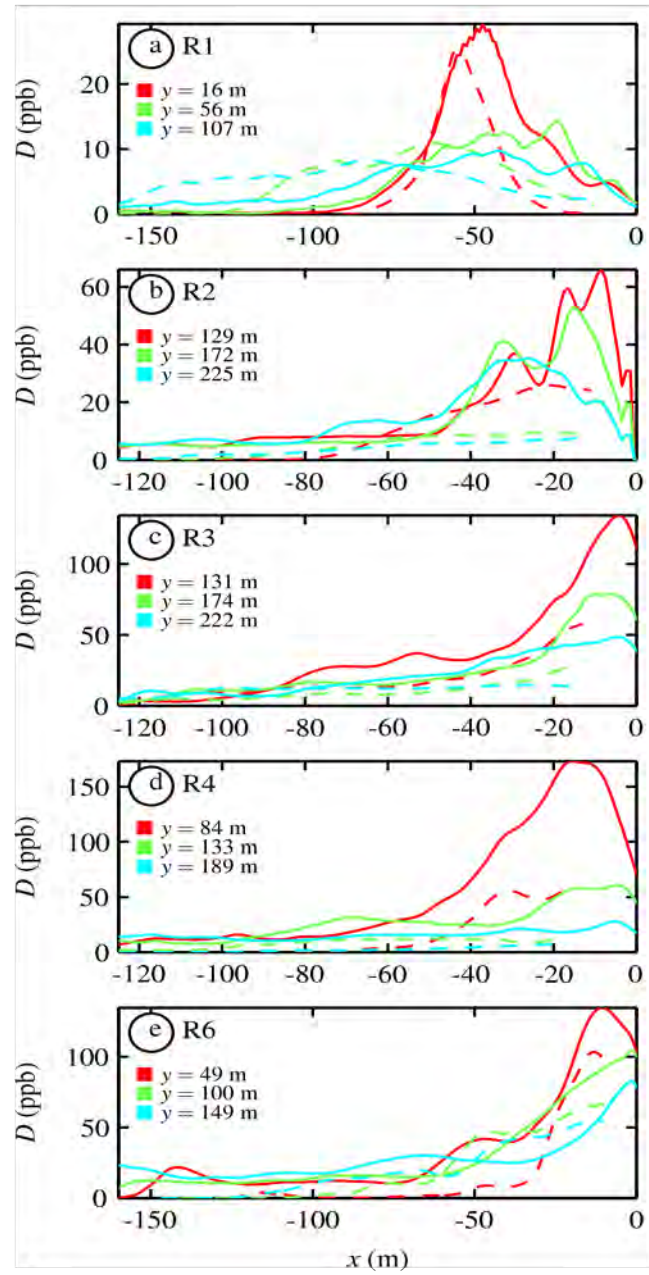
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Figure 4. Modeled $D^{(A)}$ (solid) and observed $D^{(\mathrm{obs})}$ (dashed) mean tracer profiles versus x for (a) R1, (b) R2, (c) R3, (d) R4, and (e) R6, with alongshore distance y from the source indicted by the legend in each panel. Observed transects extend from seaward of the tracer plume to the inner transect edge x_{in}.
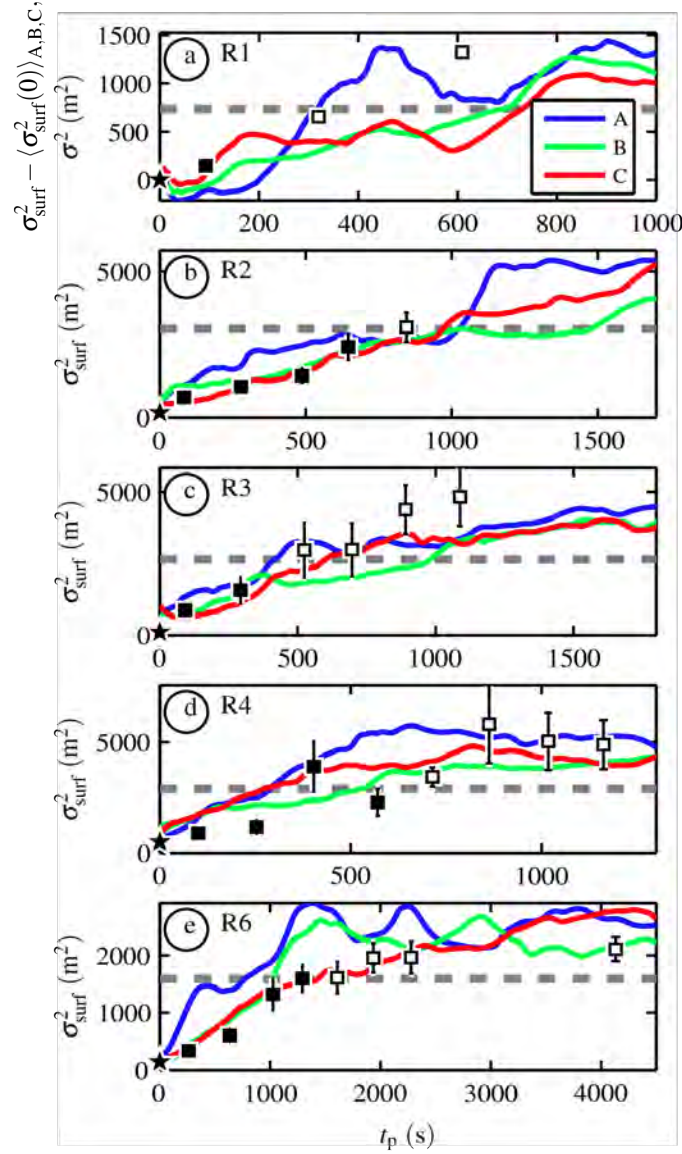
Figure 5 Modeled (color curves) and observed (black or white squares with error bars) squared cross-shore length scale σ^2_{surf} versus plume age t_{p} for releases (b) R2, (c) R3, (d) R4, and (e) R6, and (a) $\sigma^{2\,(\text{A,B,C})}_{\text{surf}}(t_{\text{p}}) - \langle \sigma^{2\,(\text{A,B,C})}_{\text{surf}}(t_{\text{p}} = 0)\rangle_{\text{A,B,C}}$ (modeled) and σ^2 (observed) for release R1. Tracer profiles that are well contained in the surfzone, where κ_{xx} is fit, are indicated by black squares (observed) or the region below the dashed gray line (model) with $\mathcal{R} < 0.55$. The $\sigma^{2\,(\text{obs})}_{\text{surf}}$ initial conditions (assuming a δ-function at $t_{\text{p}} = 0$) are indicated by the black stars. The mean $\sigma^2_{\text{surf}}(t_{\text{p}})$ skill over releases R2, R3, R4 and R6 is 0.92.
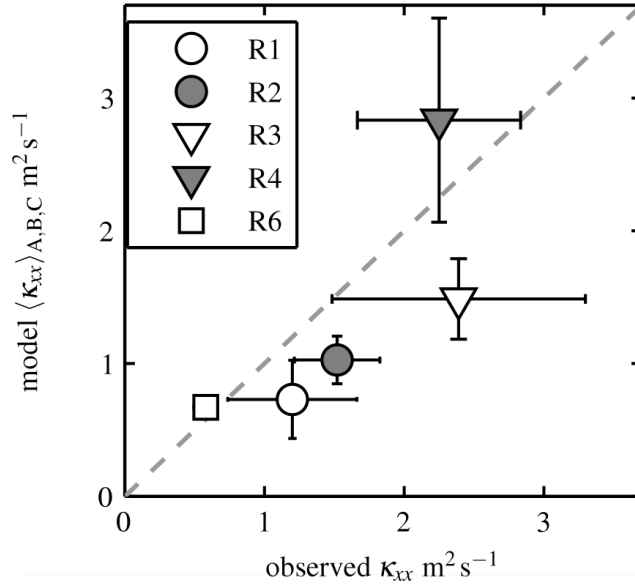
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Figure 6 Mean modeled $\langle \kappa_{xx} \rangle_{A,B,C}$ versus observed $\kappa_{xx}^{(obs)}$, with a dashed line indicating perfect agreement. The $\kappa_{xx}^{(obs)}$ error bars are estimated from the $\sigma_{surf}^{2\,(obs)}$ versus t_p fit slope error [*Clark et al.*, 2010], and model $\langle \kappa_{xx} \rangle_{A,B,C}$ error bars are the combination of fit slope errors and the variation in $\kappa_{xx}^{(A,B,C)}$ magnitudes. The skill is 0.40.

Figure 7: Aerial photograph during the IB09 plume experiment with South swell. Dye injected continuously near the shoreline was advected northward (toward the image top) by the breaking-wave driven alongshore current. A fixed array of instruments (downcoast of the Imperial Beach Pier, upper left) spanned from the shoreline to about 5m depth. The jetski sampling pattern was similar to Huntington Beach (figure 1) but spanned several km of dye plume (figure 8).
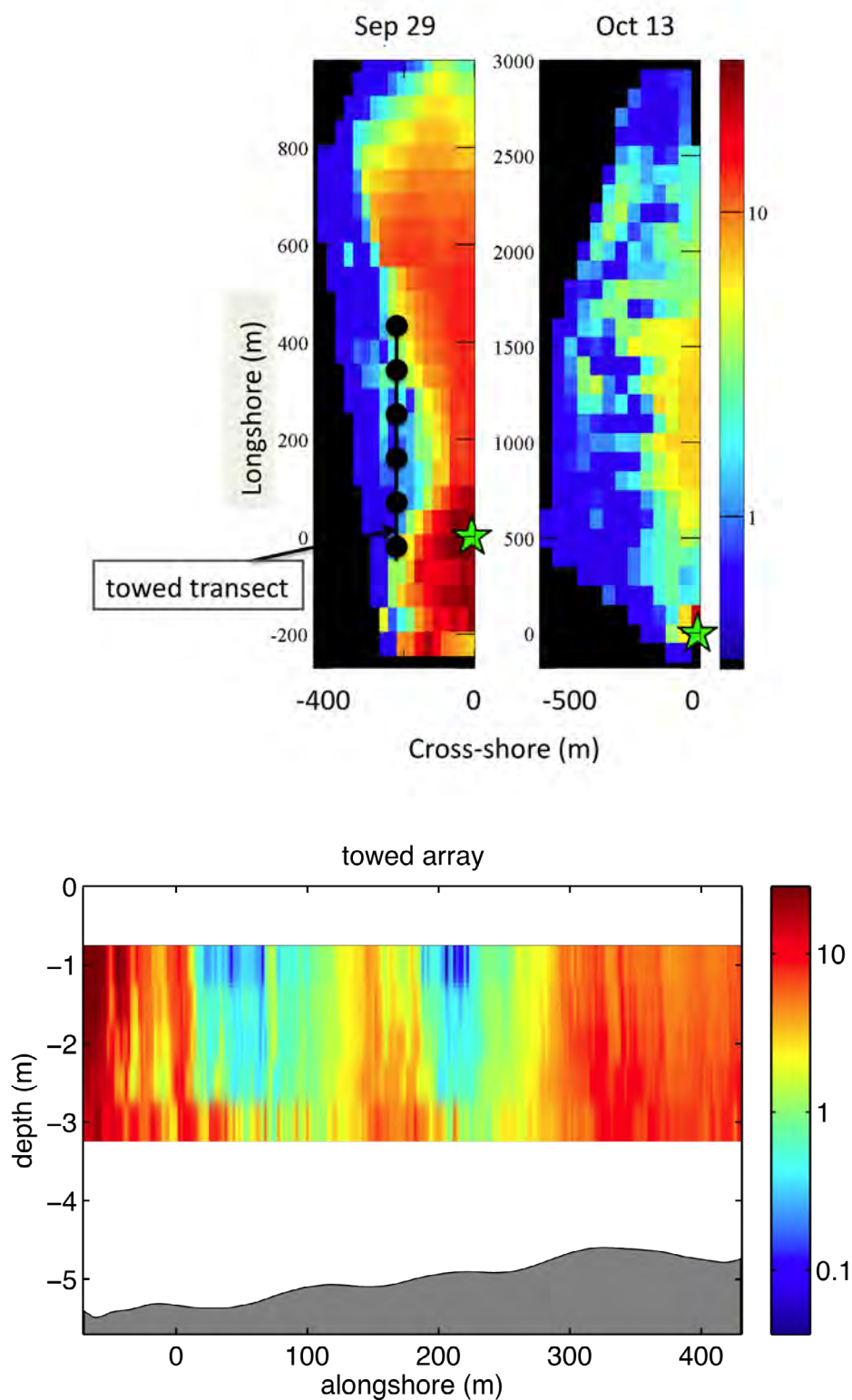
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Figure 8: IB09 (upper) plan view of dye concetration maps on 2 days. On Oct 13 (right), the plume is detectable 2.5km downstream from the dye source (green star). The black line in Sep 29 (left) shows the alongshore transect of (lower) dye concentration versus depth and alongshore location